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To what extent does organic farming rely on nutrient inflows from conventional farming?

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Abstract

Organic farming is increasingly recognized as a prototype for sustainable agriculture. Its guidelines ban the use of artificial fertilizers. However, organic farms may import nutrients from conventional farming through material exchanges. In this study, we aimed at estimating the magnitude of these flows through the quantification of nitrogen, phosphorus and potassium inflows from conventional farming to organic farming. Material inflows and outflows were collected for two cropping years on 63 farms. The farms were located in three French agricultural districts distributed over a gradient of farming activity defined by both the stocking rate and the ratio of the farm area under arable crops. Our results showed that on average, inflows from conventional farming were 23%, 73% and 53% for nitrogen, phosphorus and potassium, respectively. These inflows were strongly determined by the farm production systems. However, for farms similar in terms of production systems, the inflows also depended on the local context, such as the proximity of organic livestock farms: the reliance of organic farming on conventional farming was lower in mixed than in specialized districts. These results highlight the necessity to quantify the contribution of nutrient inflows from conventional farming when assessing organic farming and development scenarios.

Keywords: organic farming, conventional farming, nutrient flows, manufactured fertilizers, nutrient balance

 Online supplementary data available from stacks.iop.org/ERL/8/044045/mmedia

1. Introduction

Organic farming may be considered as a prototype of sustainable farming (Reganold *et al* 2001, IAASTD 2009). Recent meta-analyses of the literature demonstrated that organic yields of individual crops are similar to those

of conventionally managed crops when good management practices are applied (Seufert *et al* 2012). In addition, organic farming practices generally have less harmful environmental effects than conventional farming practices (Hansen *et al* 2001) when expressed on an area basis (Tuomisto *et al* 2012). In particular, as is the case in Europe, most organic farming guidelines exclude the use of artificial fertilizers such as manufactured nitrogen (N) fertilizers and acid-treated phosphorus (P) and potassium (K) mineral rocks. Therefore, organic farming accounts for lower greenhouse gas emissions



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and lower energy consumption than conventional farming because of the high environmental cost associated with producing conventional artificial fertilizers (Haas *et al* 2001). Consequently, scenarios have been proposed to extend organic farming on larger scales, from catchment scale (Thieu *et al* 2010) to country scale (Pelletier *et al* 2008).

Nutrients may be supplied to organic farms through different processes. According to European organic regulations, animals must be fed with organically produced grains and fodders (European Commission 2008). However, some derogations exist to allow the use of conventionally produced feedstuff when organic supply is low (OFIS 2013). For crop fertilization, European regulations recommend to use organically produced animal manure but allow the use of conventionally produced manure, provided that it is not the output of 'factory farming'. By-products of the meat industry such as feather and bone meal can be used as fertilizers, regardless of their origin. Finally, organic farms are allowed to import conventionally produced straws for animal beddings. Such inflows represent transfers of nutrients initially contributed by manufactured fertilizers and have to be accounted for: (i) when comparing the environmental impacts of conventional and organic farming; and (ii) when designing scenarios of massive conversion to organic farming. They may be of critical importance in the event that organic farming develops dramatically in the coming decades. Several authors have already pointed out that organic farms partially import nutrients from conventional farming through material exchanges (Kirchmann *et al* 2008, Oelofse *et al* 2010, Nesme *et al* 2012). However, to our knowledge, these inflows have not been quantified. In this letter, we provide a quantification of these inflows under European conditions.

In this study, we estimated the magnitude of the N, P and K inflows from conventional farming to organic farming. We first hypothesized that inflows from conventional farming are lower for N than for P and K since it is assumed that organic farmers preferentially rely on on-farm resources such as N fixation. Second, we hypothesized that inflows from conventional farming are positively correlated with farm fertilizing material demand since imports of conventionally produced manure and fertilizer are allowed, whereas imports of conventionally produced feeds and fodders are forbidden. Finally, we hypothesized that inflows from conventional farming are lower for organic farms located within mixed districts with both organic arable and livestock farming because of possible local exchanges between organic livestock and arable farms, such as manures versus straws. However, such exchanges are virtually impossible at a large scale due to the fact that animal manure is both cumbersome and difficult to transport. We assessed these hypotheses across a large range of organic farms in three French agricultural districts distributed along a gradient of both stocking rate and arable area. France was considered as a good case study of semi-intensive, highly productive agriculture, and the three agricultural districts may be considered as representative of a wide range of European agricultural conditions.

2. Material and methods

2.1. Study area and data collection

Three French agricultural districts (Lomagne, Pilat and Ribéracois; supplementary figure 1 available at stacks.iop.org/ERL/8/044045/mmedia) distributed along a gradient of both stocking rate, expressed in livestock unit (LU) per ha of agricultural area, and arable area, expressed in % of the agricultural area, were considered in this study (supplementary table 1 available at stacks.iop.org/ERL/8/044045/mmedia). Lomagne is specialized in arable production with 49%, 29% and 1% of the total agricultural area (organic and conventional farming combined) under cereals, oilseed and protein crops, respectively (Agreste 0000), due to favourable climate and soil conditions. Irrigation is regularly provided to some crops (e.g., soybean) due to low annual rainfall (600 mm) and dry summers. The stocking rate is low (0.20 LU ha^{-1}), but a small number of farms are highly specialized in poultry production. Pilat is specialized in bovine dairy production and has a high stocking rate (1.15 LU ha^{-1}). Arable crop cultivation is limited by acidic soils, a relatively short growing season and a hilly terrain (from 140 to 1432 m asl). As a consequence, land use mainly concerns permanent and temporary grasslands (55% and 28% of the agricultural area, respectively), with a low share of cropland (10% of the agricultural area, mainly as cereals). Finally, Ribéracois is a mixed district with both arable and animal production: 42, 13% and 13% of the agricultural area is under cereal, oilseed and protein crops, respectively, and 40% under grasslands and other fodders. Animal production primarily concerns milk-fed calves since more than 90% of the livestock is bovine, with a moderate stocking rate of 0.63 LU ha^{-1} .

In each district, more than three quarters of the organic farms were surveyed during the year 2012, for a total of 63 organic farms. Farmers were asked to provide a detailed description of their farm-gate nutrient inflows in terms of both their nature and origin. The data provided by farmers were checked by comparison with multiple written sources such as farm records, field and herd books and ledgers. The data collected referred to the cropping years 2010 and 2011.

Farms had been converted to organic farming for 2–46 years, but 75% of them had been converted for 2–11 years. In Lomagne ($n = 25$ farms) and Pilat ($n = 21$), the organic farm characteristics were similar to the regional agricultural characteristics (supplementary table 2 available at stacks.iop.org/ERL/8/044045/mmedia). In Lomagne, cropland accounted for 86% of the agricultural area of the organic farms surveyed. However, the area under protein crops was higher for the farms surveyed (25%) than for the region in general (1%). Our sample of organic farms from Lomagne included 18 arable, three poultry, two sheep, two beef and one horticulture farm. Livestock farms exhibited low to moderate stocking rates (supplementary figure 2 available at stacks.iop.org/ERL/8/044045/mmedia). In Pilat, the organic farms exhibited relatively high stocking rates (average of 0.93 LU ha^{-1}), close to the regional value

(1.15 LU ha⁻¹). The organic farms surveyed in Pilat were specialized in bovine dairy production, except for two poultry and one horticulture farm. Finally, in Ribéracois ($n = 17$), organic farms were more specialized in animal production than the region in general. For example, cropland accounted for only 17% of the agricultural area of the farms surveyed, compared to 55% for the region in general. Our sample of organic farms from Ribéracois included seven beef, six goat and ovine dairy, three arable and one poultry farm. Livestock farms exhibited moderate stocking rates (average of 0.6 LU ha⁻¹).

2.2. Nutrient inflow modelling

For each farm, the N, P and K farm-gate inflows were estimated as follows: inflows were nutrients embedded in trade products (fertilizing materials, feedstuffs, mineral P supplements, fodders and straws), plus atmospheric N deposition and biological N fixation. Inflows related to soil nutrient mining were not considered in this study.

Nutrient inflows through trade products were calculated by multiplying each product input and output by their corresponding N, P and K content (Agabriel 2007, Vilain 2008, COMIFER 2009). Total atmospheric N deposition (wet and dry deposition of NH₄⁺ and NO₃⁻) was estimated from the French National N Deposition Survey (ICP Forests 2012). The biological N fixation was estimated using the model proposed by Høgh-Jensen *et al* (2004). Estimation of biological N fixation was based on the total N amount in leguminous crop biomass, multiplied by the ratio between the amount of symbiotically fixed N and the total N amount in the crop biomass.

Five origins were assigned to the nutrient inflows: (1) N from the atmosphere (N deposition and biological N fixation); (2) N, P and K from organic farming, i.e., supplied by organic farms through trade products; (3) N, P and K from conventional farming, i.e., supplied by conventional farms through trade products; (4) P and K from mineral sources (mineral P supplements and untreated, raw mineral P and K fertilizers, authorized in organic farming); and (5) N, P and K from urban sources (green waste compost). N inflows through atmospheric deposition were the only inflows totally beyond the control of organic farmers. Some organic farms imported fertilizers made from by-products of the meat industry. These by-products came from both organic and conventional farming, and the ratio of nutrients from organic farming in these fertilizers was estimated as the ratio between the number of organically bred animals (AgenceBio 0000) and the total number of animals in France (Agreste 0000), taking the contribution of each animal species to the composition of these fertilizers into account (SIFCO 2011). This ratio was estimated at 2% (data not shown). Hereafter, the term fertilizer refers both to fertilizers made from meat by-products and to mineral fertilizers. All the results were presented as the average of the cropping years 2010 and 2011 since discrepancies between the two years were low (data not shown).

2.3. Farm classification according to fertilizing material demand

The farms were classified into six clusters based on both their stocking rate (in livestock unit per ha of agricultural area, proxy of on-farm manure production) and the ratio of the farm area under cereal and oilseed crops (in %, proxy of the area to be fertilized) using Ward's clustering method (Nowak *et al* 2013). For each farm, we defined the ratio of nutrient inflows from conventional farming to organic farming (RCF, in kg kg⁻¹) as the ratio of inflows from conventional farming to the total inflows. The mean RCFs were then computed for each cluster and compared with a Kruskal–Wallis post hoc test. Data treatments were performed with R software (R Development Core Team 2009).

3. Results

3.1. Average farm-gate nutrient inflows

Over the whole sample, average farm-gate N, P and K inflows were 87, 9 and 16 kg ha⁻¹ year⁻¹, respectively (figure 1). Inflows from conventional farming were 23%, 73% and 53% of the N, P and K inflows, respectively, compared to 12%, 21% and 30% for inflows from organic farming. As expected, inflows from conventional farming were lower for N than for P and K due to large N inflows from atmospheric sources (63% of the N inflows). Inflows from conventional farming were lower for K than for P because of larger K inflows through organic fodders and from mineral sources. Imports from urban sources were low (less than 2% for each of the three nutrients).

Nutrients entered the organic farms mainly through fertilizing materials (manures and fertilizers) and, to a lesser extent, through feedstuffs, fodders and straws (figure 2). More than 80% of nutrient inflows through manures (82%, 85% and 81% for N, P and K, respectively) and more than 95% of N and P inflows through fertilizers came from conventional farming, whereas 61% of K inflows through fertilizers came from mineral sources. Approximately half of the fodders and straws came from conventional farming, whereas all of the feedstuffs came from organic farming.

3.2. Effect of farm production systems

The farms were classified into six clusters that were at least partly independent of the three study areas (table 1). The stocking rate increased from Cluster 1 to Cluster 6 (from 0 to 1.2 LU ha⁻¹), whereas the percentage of the agricultural area under cereal, oilseed and protein crops decreased from Cluster 1 to Cluster 6 (from 98 to 9%). Therefore, farms in Cluster 1 were typically stockless, arable farms, whereas those in Cluster 6 were moderately intensive dairy, beef or poultry farms. RCFs were the highest for farms in Cluster 1 (figure 3): for these farms, RCFs were 62%, 99% and 96% of N, P and K inflows, respectively. RCFs decreased from Cluster 1 to Cluster 6 (down to 3%, 19% and 27% for N, P and K, respectively, for Cluster 6); RCF was lower in livestock farms (Clusters 4–6) than in arable or farms with low stocking rates (Clusters 1–3). Overall, stockless farms had significantly higher RCFs than livestock farms ($P < 0.1$).

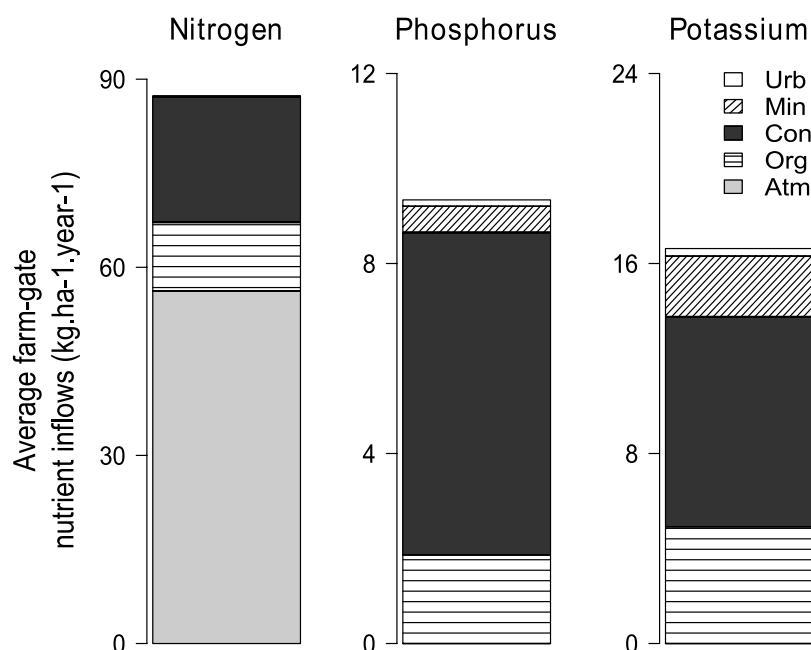


Figure 1. Origin of the farm-gate nutrient inflows for the 63 sampled organic farms. The data refer to the period 2010–2011. Atm refers to N from the atmosphere; Org refers to the N, P and K from organic farming; Con refers to the N, P and K from conventional farming; Min refers to the P and K from mineral sources; Urb refers to N, P and K from urban sources.

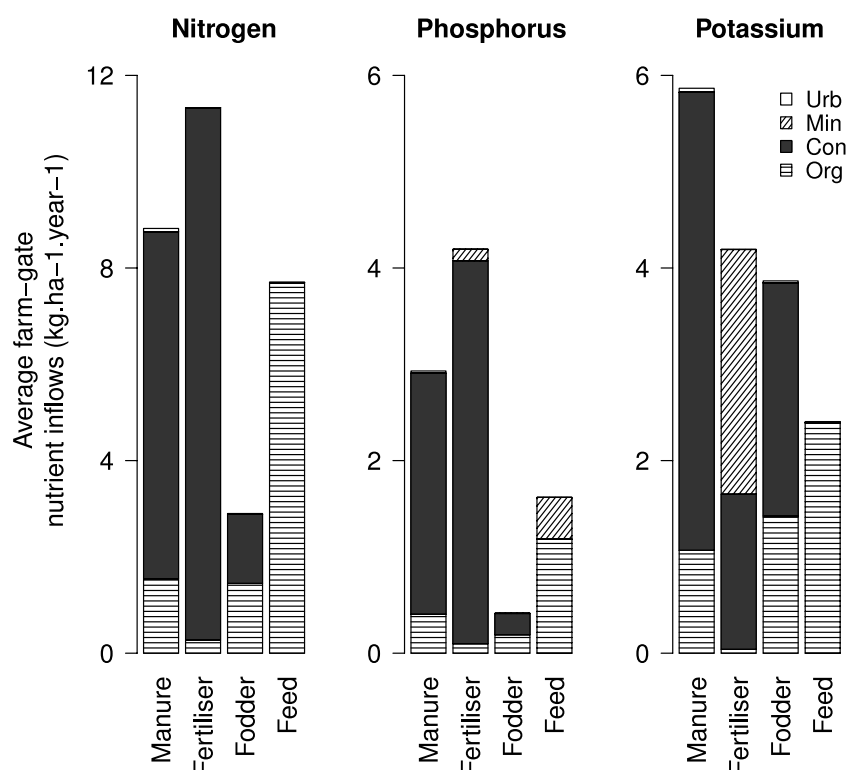


Figure 2. Nature of the farm-gate nutrient inflows for the 63 sampled organic farms. The date refer to the period 2010–2011. Manure refers to manures and compost; Fertiliser refers both to fertilizers made from meat by-products and to mineral fertilizers; Fodder refers to fodders and straws; Feed refers to feedstuffs, including mineral P supplements. For Org, Con, Min and Urb, please refer to figure 1.

3.3. Effect of regional farming context

To assess the effect of the regional farming context, farms with similar production systems but within different districts

were selected: Clusters 2 and 3 included a total of 22 farms, with 15 in Lomagne and six in Ribéracois. The ratio of N, P and K from conventional farming was higher for farms in Lomagne than for those in Ribéracois (figure 4): in Lomagne,

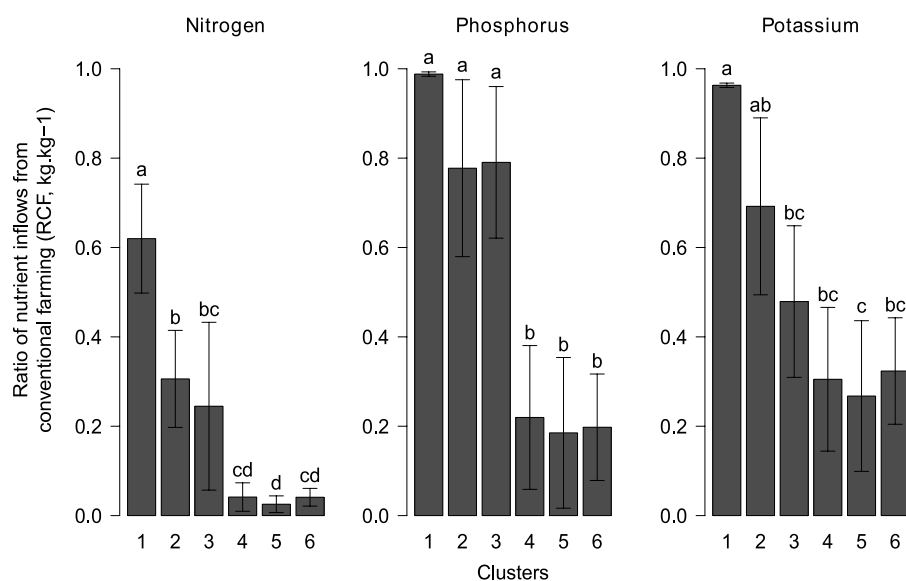


Figure 3. Ratio of nutrient inflows from conventional farming (RCF) for the six farm clusters. The error bars represent the standard deviations. Clusters with different letters are significantly different according to the Kruskal–Wallis post hoc test at a 10% level.

Table 1. Average farm characteristics per cluster. The data refer to the years 2010 and 2011.

		Clusters					
		1	2	3	4	5	6
Total number of farms		9	17	5	12	10	10
Of which, # in	Lomagne	9	13	2	1	0	0
	Ribéracois	0	4	2	8	0	3
	Pilat	0	0	1	3	10	7
Stocking rate (LU ha ⁻¹ year ⁻¹)		0.00	0.12	0.05	0.62	0.89	1.22
% of the area of organic farms surveyed under	Cereal, oilseed and protein crops	98	68	1	16	10	9
	Grasslands and other fodders	1	30	56	83	90	90
	Other (e.g., horticultural crops)	1	2	43	1	0	1

organic arable farms imported manure from conventional, neighbouring, highly specialized poultry farms with high manure surpluses (table 2). Conversely, in Ribéracois, organic arable farms sourced manure from organic fungi production farms. They also imported large amounts of mineral K fertilizer and small amounts of green waste compost. This resulted in the absence of conventional manure inflow in Ribéracois (table 2).

4. Discussion and conclusion

4.1. Summary of the results and consequences for organic farming regulations

Results showed that nutrient flows from conventional to organic farming were 23%, 73% and 53% of the N, P and K farm-gate inflows in our sample, respectively (figure 1). These inflows were mostly due to manure and fertilizer import into organic farms (figure 2) and were thus higher in farms with no or low stocking rates (figure 3), which are quite common in Europe (e.g., 66% of the organic farms were stockless farms in France in 2011) (AgenceBio 0000). Nutrient supply from conventional to organic farms was also linked to the regional

diversity in organic production (figure 4): local exchanges of organic products (e.g., manure, feedstuffs and straws) among organic farms were possible in diversified districts but were virtually impossible in highly specialized agricultural districts (table 2). Finally, it can be observed that N inflows from conventional farming were lower than for P and K due to massive N inflows from legume crops.

Nutrient inflows from conventional farming to organic farms through material exchanges have already been mentioned in previous studies (Kirchmann *et al* 2008, Oelofse *et al* 2010, Nesme *et al* 2012) but, to the best of our knowledge, have never been quantified at the farm scale. Oelofse *et al* (2013) reported that approximately 25% of nutrient inflows to organic crops through manures came from conventional farming in Danish organic farms in 2011. However, these figures are not really comparable to our results because they included on-farm organically produced manure, whereas our results referred to farm-gate nutrient inflows only. Kirchmann *et al* (2008) also reported in their review of seven organic farms in Austria and Sweden that 75% of organic mixed farms imported fodders from conventional farming. Overall, these results illustrate a general concern in Europe about the reliance of organic farming on conventional farming.

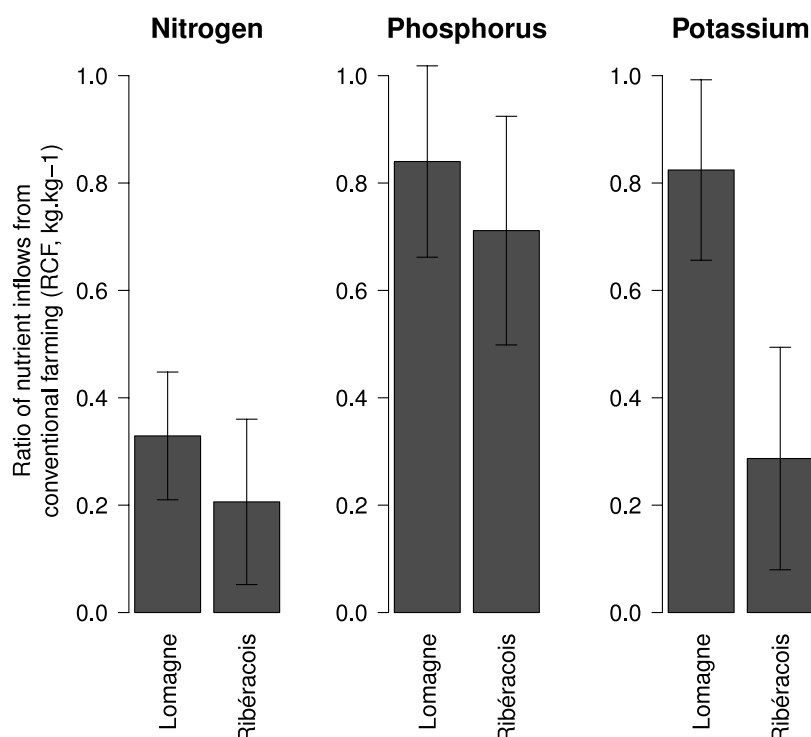


Figure 4. Ratio of nutrient inflows from conventional farming (RCF) for the organic farms in clusters 2 and 3 ($n = 15$ and six farms in Lomagne and Ribéracois, respectively). The error bars represent the standard deviations.

Different options may be explored to reduce the reliance of organic farming on nutrients from conventional farming. First, European organic regulations could be stricter, in particular, concerning conventional manure, which is allowed in organic production provided that it does not come from ‘factory farms’ (European Commission 2008). But the regulations suffer from a poor definition of such farms and stricter definition could be adopted. Second, nutrient imports from conventional sources into organic farms may be limited by national regulations. For example, Denmark has decided (i) to set a maximum of $70 \text{ kg N ha}^{-1} \text{ year}^{-1}$ that can be sourced from conventional manure, and (ii) to ban the use of conventional materials in organic farming by 2022 (Oelofse *et al* 2013). However, our results suggested that such phasing out may cause some nutrient supply shortages for arable farms. Third, alternative nutrient sources such as sewage sludge may be considered (Oelofse *et al* 2013). Indeed, these products are currently not allowed in organic farming but they represent a considerable potential nutrient supply, for P in particular, and we reported very low inflows of nutrients from urban sources to organic farms. However, these products may raise important health issues due to their potential contamination by trace elements and pharmaceutical drugs. Finally, our results showed that nutrient inflows from conventional to organic farms were lower in mixed districts with both arable and livestock organic farming. This suggests that lower reliance of organic farming on conventional farming may be achieved through increased diversification and integration of organic activities at the district scale, e.g., through farm partnerships (Nauta *et al* 1999). However, additional research efforts are required to model the effects of

farming diversity at the district scale on nutrient flows and the resulting farm-gate budget.

4.2. Consequences for the assessment of organic farming and future food production scenarios

Our results suggest that organic farming strongly relies on conventional farming, especially for P and in the case of stockless farming. This should be of interest for future scenarios on global food production. Indeed, if two recent meta-analyses showed that organic crop yields are lower than conventional crop yields, the gap is relatively low, with organic crop yields ranging from 75% (Seufert *et al* 2012) to 80% of conventional crop yields (De Ponti *et al* 2012). Moreover, organic yields may be increased under good nutrient supply conditions, suggesting that nutrient management is a key issue in organic production (Berry *et al* 2002, Seufert *et al* 2012). Scenarios of 100% organic farming have been designed as well, both at the country scale (Pelletier *et al* 2008) and at the regional scale (Thieu *et al* 2010). However, these scenarios poorly considered the crop nutrition aspects and none of them has taken the reliance of organic farming on conventional farming into account. The area under organic farming at this time is only 0.7, 2.2 and 3.5% of the total agricultural area at the global, European and French scales, respectively (FAO 2013). Therefore, if the area under organic farming was to undergo a dramatic increase, feedstuff and fodder supply from organic farming could possibly increase, but stronger competition for manure and fertilizer from conventional farming could also be expected, possibly resulting in a decrease in organic crop yields.

Table 2. Nature of the farm-gate nutrient inflows for the 63 sampled organic farms in kg ha⁻¹ year⁻¹. The data refer to the years 2010 and 2011.

District	Product	Organic farming	Conventional farming	Mineral sources	Urban sources
<i>Nitrogen inflows</i>					
Lomagne	Manure	0	18	0	0
	Fertilizer	1	23	0	0
	Fodder and straw	0	0	0	0
	Feedstuff	3	0	0	0
	<i>Total</i>	<i>4</i>	<i>41</i>	<i>0</i>	<i>0</i>
Ribéracois	Manure	4	0	0	0
	Fertilizer	0	5	0	0
	Fodder and straw	3	3	0	0
	Feedstuff	7	0	0	0
	<i>Total</i>	<i>14</i>	<i>8</i>	<i>0</i>	<i>0</i>
Pilat	Manure	0	0	0	0
	Fertilizer	0	1	0	0
	Fodder and straw	3	2	0	0
	Feedstuff	17	0	0	0
	<i>Total</i>	<i>20</i>	<i>3</i>	<i>0</i>	<i>0</i>
<i>Phosphorus inflows</i>					
Lomagne	Manure	0	6	0	0
	Fertilizer	0	9	0	0
	Fodder and straw	0	0	0	0
	Feedstuff	1	0	0	0
	<i>Total</i>	<i>1</i>	<i>15</i>	<i>0</i>	<i>0</i>
Ribéracois	Manure	1	0	0	0
	Fertilizer	0	1	0	0
	Fodder and straw	0	1	0	0
	Feedstuff	1	0	0	0
	<i>Total</i>	<i>2</i>	<i>2</i>	<i>0</i>	<i>0</i>
Pilat	Manure	0	0	0	0
	Fertilizer	0	0	1	0
	Fodder and straw	0	0	0	0
	Feedstuff	3	0	1	0
	<i>Total</i>	<i>3</i>	<i>0</i>	<i>2</i>	<i>0</i>
<i>Potassium inflows</i>					
Lomagne	Manure	0	12	0	0
	Fertilizer	0	3	1	0
	Fodder and straw	0	0	0	0
	Feedstuff	1	0	0	0
	<i>Total</i>	<i>1</i>	<i>15</i>	<i>1</i>	<i>0</i>
Ribéracois	Manure	3	0	0	0
	Fertilizer	0	1	6	0
	Fodder and straw	2	5	0	0
	Feedstuff	2	0	0	0
	<i>Total</i>	<i>7</i>	<i>6</i>	<i>6</i>	<i>0</i>
Pilat	Manure	0	0	0	0
	Fertilizer	0	0	0	0
	Fodder and straw	3	2	0	0
	Feedstuff	6	0	0	0
	<i>Total</i>	<i>9</i>	<i>2</i>	<i>0</i>	<i>0</i>

Our results may also be of interest for future organic farming assessment. Indeed, life cycle analysis has been widely used to assess both organic and conventional farms (Tuomisto *et al* 2012). For example, Haas *et al* (2001)

reported that energy consumption per milk unit is 56% lower in organic farming compared to conventional farming. Greenhouse gas emissions have been shown to be lower in organic farming than in conventional farming in asparagus

(Zafiriou *et al* 2012), peach (Michos *et al* 2012) and cherry production (Litskas *et al* 2011) when expressed on an area basis. These lower environmental impacts are due to the high environmental costs associated with producing conventional, manufactured fertilizers, especially N fertilizers. However, accounting for nutrient flows from conventional to organic farming and, therefore, indirect reliance of organic farming on manufactured fertilizer, may modify the previous assessment results. Nevertheless, all nutrient inflows from conventional farming may not come from manufactured fertilizers since some N may come from biological N fixation and some nutrients may come from the natural fertility of the soil. Additional studies are therefore required to discriminate between nutrient inflows from conventional farming and from manufactured fertilizers.

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